



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
ELECTRIC POWER AND MACHINES DEPARTMENT

ECONOMIC DISPATCH USING NEW OPTIMIZATION METHODS

BY
DINA MOHAMED SAID AYAD

B. SC., Ain Shams University
A thesis submitted to Ain Shams University for the requirements of the degree of
MASTER OF SCIENCE

IN
ELECTRICAL ENGINEERING

Under supervision of

Prof. Dr. Almoataz Youssef Abdelaziz

Electrical Power and Machine Department
Faculty of Engineering
Ain Shams University

Dr. Nabil Mohamed Hamed

Electrical Power and Machine Department
Faculty of Engineering
Ain Shams University

Cairo 2016

Acknowledgement

In the name of Allah, the Most Gracious and the Most Merciful

Foremost, all praises to Allah for his blessing and the strengths in completing this thesis.

I would like to express my sincere gratitude to my supervisors **Prof. Dr. Almoataz Y. Abdelaziz** and **Dr. Nabil M. Hamed** for the mentorship and guidance throughout this study. Their patience, motivation and constructive comments helped me shape this into its final form.

I would like to extend my thanks to **Eng. Hatem Waheed** the executive manager of **Egypt ERA** -where I work- who showed an unwavering support. Of course I can't forget **Eng. Ahmed Sallam**, **Eng. Mohamed Zaki** and **Eng. Fatma Sayed** who offered collegial guidance and support.

My profound gratitude goes to **my parents, Mr M. Said Ayad and Dr. Ratiba El Ockr**, my priceless brothers, engineers; **Amr, Hani** and **Karim**, a special thanks to my beloved husband **Eng. Mohamed**, I'm indebted to them for supporting me spiritually throughout my life, for their endless love, prayers and continuous encouragement.

Last but not least, tribute and appreciation to my work colleagues, engineers; **Nada, Sherein, May** and **Reem**, my friends **Amira** and **Rania**, in addition to all those their names do not appear here who have indirectly contributed to the successful completion of this study.

Dina Said

ABSTRACT

The Economic Dispatch (ED) optimization is one of the fundamentals to assure reliability and security of power systems. The objective of ED is to dispatch the load among units in an economic way, at the same time operational, physical constraints are satisfied. In today's world, environmental concerns arise as a result of the emission produced from fossil- fueled generators, which changes the classical ED problem to a multi-objective Economic Emission Dispatch (EED) problem.

This thesis addresses the optimization of the EED problem for thermal power plants subjected to the power balance equality constraint and generator operating limits. For more practical representation of the systems, the transmission losses are taken into consideration, in addition to valve loading effect.

Much research recently has been pertained to EED problem. Traditional techniques show good capability of solving the economic emission dispatch problem, but they fail to achieve satisfactory success for large scale problems or in presence of nonlinearities and non-smooth characteristics as valve-point effects. As also environmental criteria are added, the optimum schedule obtained might not be the best and the complexity increase as EED has conflicting objectives, since the emission's minimization is in contradiction to that of cost.

Novel techniques have proven lately to be fast and reliable for solving EED problem. In this work two recent meta-heuristic approaches are introduced, Bacterial Foraging Optimization Algorithm (BFOA) and Shuffled Frog Leaping Algorithm (SFLA). The BOFA is designed to handle complex and non-gradient objective function, where the bacteria with good foraging strategy survive. While the SFLA mimics the evolution of a group of frogs, which are partitioned and share information globally to get the optimum solution.

A Comparison is set between the two methods and other approaches after being applied to different systems with different complexity using MATLAB® program, to demonstrate the effectiveness of both algorithms. The proposed approaches showed promising results to the solution of the economic emission dispatch EED problem.

TABLE OF CONTENTS

Table of Contents	I
List of Tables	III
List of Figures	VII
List of Symbols	X
List of Abbreviations	XII
CHAPTER 1	
INTRODUCTION	1
1.1 General	1
1.2 Importance of Economic Dispatch	1
1.3 Input – Output Characteristics of Generator Units	1
1.4 Economic Dispatch Problem	2
1.5 Non-convex Economic Dispatch	4
1.6 Emission Dispatch	5
1.7 Multi-Objective Economic Emission Dispatch	6
1.8 The objectives	8
1.9 Contribution	8
1.10 Thesis outline	8
CHAPTER 2	
LITERATURE REVIEW	10
2.1 General	10
2.2 Introduction	10
2.3 Literature survey	10
2.4 Bacterial Foraging Optimization Algorithm (BOFA)	16
2.5 Shuffled Frog Leaping Algorithm	18
CHAPTER 3	
OPTIMIZATION ALGORITHMS	22
3.1 Introduction	22

3.2 Bacteria Foraging Optimization Algorithm	22
3.2.1. Bacterial Foraging phenomenon	22
3.2.2. Bacterial foraging for optimization	24
3.2.3. BFOA Steps of Implementation:	27
3.2.4. Effect of BFOA parameters' selection	28
3.3 Shuffled Frog Leaping Algorithm	30
3.3.1. Background	30
3.3.2. Steps of implementing the shuffled frog-leaping algorithm	31
3.3.3. Memetic evolution of the shuffled frog-leaping algorithm	35
3.3.4. Effect of SFLA parameters' selection	36
 CHAPTER 4	
APPLICAION: RESULTS AND ANALYSIS	38
4.1 Introduction	38
4.2 Constraint's handling using weighted average method	39
4.3 Simulation results and analysis for the studied systems	42
4.3.1. Classical ED optimization problem	42
4.3.2. Non-convex ED optimization problem	68
4.3.3. Emission Economic Dispatch optimization problem	79
 CHAPTER 5	
CONCLUSION AND FUTURE WORK	95
5.1 General	95
5.2 Main Contributions	95
5.3 Future Work	96
 REFERENCES	100
List of Publications	103
Appendix 1	104
Appendix 2	109

LIST OF TABLES

Table	Page
Table 4.1 BFOA results for 3 generator system at $P_D = 450$ MW	42
Table 4.2 SFLA results for 3 generator system at $P_D = 450$ MW	44
Table 4.3 BFOA results for 3 generator system at $P_D = 900$ MW	46
Table 4.4 SFLA results for 3 generator system at $P_D = 900$ MW	46
Table 4.5 Comparing BFOA to others for 3 generator system at $P_D = 450$ MW	47
Table 4.6 Comparing BFOA to others for 3 generator system at $P_D = 900$ MW	47
Table 4.7 Comparing SFLA to others for 3 generator system at $P_D = 450$ MW	48
Table 4.8 Comparing SFLA to others for 3 generator system at $P_D = 900$ MW	48
Table 4.9 BFOA results for 6 generator system at $P_D = 700$ MW	49
Table 4.10 SFLA results for 6 generator system at $P_D = 700$ MW	50
Table 4.11 Results for best results with the 6 generator system at $P_D = 700$	51
Table 4.12 Statistical comparison between BFOA and SFLA for case study 2	52
Table 4.13 BFOA results for 13 generator system at different S values	54
Table 4.14 BFOA results for 13 generator system at different N_c values	55
Table 4.15 BFOA results for 13 generator system at different N_s values	56
Table 4.16 BFOA results for 13 generator system at different N_{re} values	57
Table 4.17 BFOA results for 13 generator system at different N_{re} values	58

Table 4.18	BFOA results for 13 generator system at different Ped values	59
Table 4.19	BFOA results for 13 generator system at different C values	60
Table 4.20	SFLA results for 13 generator system at different N values	61
Table 4.21	SFLA results for 13 generator system at different M values	62
Table 4.22	SFLA results for 13 generator system at different SI values	63
Table 4.23	SFLA results for 13 generator system at different Smax values	64
Table 4.24	SFLA results for 13 generator system at different IE values	65
Table 4.25	Comparing BFOA to others for 13 generator system at PD= 1800 MW	66
Table 4.26	Comparing SFLA to others for 13 generator system at PD= 1800 MW	67
Table 4.27	BFOA results for 3 generator system with valve loading effect at PD= 850 MW	68
Table 4.28	SFLA results for 3 Generator system with valve loading effect at PD= 850 MW	68
Table 4.29	Statistical comparison between BFOA and SFLA for case study 4	69
Table 4.30	Comparison of BFOA results for including and excluding valve loading effect for case study 4	70
Table 4.31	Comparison of SFLA results for including and excluding valve loading effect for case study 4	70
Table 4.32	BFOA results for 13 Generator system with valve loading effect at PD= 1800 MW	71

Table 4.33	Statistical data for BFOA regarding case study 5	72
Table 4.34	SFLA results for 13 generator system with valve loading effect at PD= 1800 MW	73
Table 4.35	Statistical data for SFLA regarding case study 5	74
Table 4.36	Comparison of BFOA results for including and excluding valve loading effect for case study 5	75
Table 4.37	Comparison of SFLA results for including and excluding valve loading effect for case study 5	76
Table 4.38	BFOA results for 40 generator system with valve loading effect at PD= 10500 MW	77
Table 4.39	SFLA results for 40 generator system with valve loading effect at PD= 10500 MW	78
Table 4.40	BFOA results best cost for EED of IEEE 30 bus generator system	79
Table 4.41	BFOA results best emission for EED of IEEE 30 bus generator system	80
Table 4.42	Comparison of BFOA and different methods for the best cost	80
Table 4.43	Comparison of BFOA and different methods for the best emission	81
Table 4.44	Statistical data for cost of BFOA to other algorithms for case study 7	82
Table 4.45	Statistical data for emission of BFOA to other algorithms for case study 7	83
Table 4.46	SFLA results for best cost for EED of IEEE 30 bus generator system	84

Table 4.47	SFLA results best emission for EED of IEEE 30 bus generator system	84
Table 4.48	Comparison of SFLA and different methods for the best cost	85
Table 4.49	Comparison of SFLA and different methods for the best emission	86
Table 4.50	Statistical data for cost of SFLA to other algorithms for case study 7	87
Table 4.51	Statistical data for emission of SFLA to other algorithms for case study 7	87
Table 4.52	BFOA results for best cost for EED of 40- generators system	88
Table 4.53	BFOA results for best emission for EED of 40-generators system	90
Table 4.54	SFLA results for best cost for EED of 40-generators system	92
Table 4.55	SFLA results for best emission for EED of 40-generators system	93
Table 4.56	Comparison of BFOA, SFLA and MBFA for 40-generator system	94

LIST OF FIGURES

Figure	Page
Fig. 1.1 Input-Output characteristics of the generating unit	2
Fig. 1.2 Fuel cost function with four valve points	4
Fig. 3.1 Chemotactic behavior of E.Coli :run and tumble	23
Fig. 3.2 Illustration of BFOA processes	26
Fig. 3.3 BFOA Flowchart	29
Fig. 3.4 An illustration of the concept of a submemplex	33
Fig. 3.5 Illustration of the SFLA	34
Fig. 3.6 Flow chart of Modified Shuffled Frog Leaping Algorithm	37
Fig. 4.1 1 st trial of 3 generator system	43
Fig. 4.2 2 nd trial of 3 generator system	43
Fig. 4.3 3 rd trial of 3 generator system	43
Fig. 4.4 4 th trial of 3 generator system	43
Fig. 4.5 5 th trial of 3 generator system	43
Fig. 4.6 SFLA convergence graph for 3 generator-system at PD= 450 MW	44
Fig. 4.7 Frogs scattering in space	45
Fig. 4.8 Frogs step in groups	45
Fig. 4.9 Memplex evolution & shuffling	45
Fig. 4.10 Two frogs are censorships	45
Fig. 4.11 Censorships are replaced	45

Fig. 4.12	Frogs reach optimal result	45
Fig. 4.13	Convergence graph for SFLA applied to 6 generators with a demand of 700 MW	50
Fig. 4.14	Fuel cost for various algorithms for case study 2	52
Fig. 4.15	Distribution of total costs of the BFOA algorithm for a load demand of 1800MW for 30 different trials	72
Fig. 4.16	Distribution of total costs of the SFLA algorithm for a load demand of 1800MW for 50 different trials	74
Fig. 4.17	Best fuel cost for BFOA and various algorithms for IEEE 30 bus generator system	81
Fig. 4.18	Best emission solution for BFOA and various algorithms for IEEE 30 bus generator system	82
Fig. 4.19	Best fuel cost for SFLA and various algorithms for IEEE 30 bus generator system	85
Fig. 4.20	Best fuel cost for SFLA and various algorithms for IEEE 30 bus generator system	86
Fig. 4.21	Results for generators 1, 3, 5	89
Fig. 4.22	Results for generators 9, 11, 13	89
Fig. 4.23	Results for generators 15,18,19	89
Fig. 4.24	Results for generators 22,24,28	89
Fig. 4.25	Results for generators 30, 34 and 38	89
Fig. 4.26	SFLA solution for gen. 1,2,3	91
Fig. 4.27	SFLA solution for gen. 8,9,10	91

Fig. 4.28	SFLA solution for gen. 17,18,19	91
Fig. 4.29	SFLA solution for gen. 23,26,28	91
Fig. 4.30	SFLA solution for gen. 33,36,38	91

List of Symbols

P_{Gi}	Net power of the i^{th} generator in MW
$F_i(P_{Gi})$	Cost function of the i^{th} generator
a_i, b_i, c_i	Cost coefficients of the i^{th} generator in $\$/\text{MW}^2$, $\$/\text{MW}$ and $\$$ respectively
N_G	Number of generating units in the system
P_D	Total demand in MW
P_{loss}	Total transmission losses in MW
B_{ij}, B_{0i}, B_{00}	Loss-coefficients of transmission loss formula
p_{Gi}^{min}	Minimal capacity of the i^{th} generator
p_{Gi}^{max}	Maximal capacity of the i^{th} generator unit
e_i, f_i	Cost coefficients of i^{th} generator reflecting valve-point loading effects
$E_i(P_{Gi})$	Total emission of the i^{th} generator
$\alpha_i, \beta_i, \gamma_i$	Emission coefficients of the i^{th} generator
ζ_i, λ_i	Pollution coefficients representing valve point effect
F_{EED}	Total cost
h_i	Price penalty factor in $\$/\text{kg}$
δ	Compromise factor for multi-objective function
w_k	The weight assigned to the k^{th} objective

For Bacterial Foraging Optimization Algorithm

i	index for i^{th} bacterium
N_s	Limits of swim length
N_{re}	Total number for reproduction steps
S	Total number of bacteria